Illinois River Upland and In-stream Phosphorus Modeling

FINAL REPORT

Submitted to

Oklahoma Department of Environmental Quality

Submitted by

Dr. Daniel E. Storm

Mr. Michael J. White

Dr. Michael D. Smolen

Department of Biosystems and Agricultural Engineering
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

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1 - Introduction

Background and Purpose

The Illinois River basin covers approximately 1,600 square miles and is divided nearly equally by the Oklahoma/Arkansas border. The Illinois River is arguable Oklahoma's most valued scenic river. The basin has been a hot bed of legal activity since 1982, reaching even the US Supreme Court in 1992. Oklahoma recently set a 0.037 mg/l phosphorus criterion for scenic rivers. Point source dischargers and the application of poultry litter are often blamed as the chief sources of phosphorus in the Illinois River.

The primary purpose of this project was to predict reductions in poultry litter application and point source phosphorus discharges which will be required to meet the 0.037mg/l Oklahoma criterion. The 0.037 mg/l criterion is calculated as a geometric mean, which tends to be more sensitive to base flow concentrations and less influenced by short duration runoff events. Reducing nonpoint source phosphorus loads has may only a minor impact the geometric mean, but is critical to meeting the beneficial uses for Lake Tenkiller. A secondary goal of this project was to evaluate the phosphorus load to Lake Tenkiller under differing point and nonpoint scenarios.

The Upland SWAT Model

The SWAT 2000 model was used to estimate erosion and nutrient loads from the upland areas of the basin. SWAT is a distributed parameter basin scale model developed by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT is included in the Environmental Protection Agency's (EPA) latest release of Better Assessment Science Integrating Point and Nonpoint Sources (BASINS).

SWAT requires a vast amount of data to properly represent a watershed. Some data are supplied as Geographic Information Systems (GIS) data; other data, such as weather or management, are typically tabular. These data were obtained from existing sources, and thus no new data were collected specifically for this project by Oklahoma State University.

The In-Stream Model

To accurately predict in-stream phosphorus concentrations, a new in-stream model was developed for use with SWAT 2000. SWAT was used to predict the flows and nutrient loads from upland areas, which were routed through the stream network by the new in-stream model. Soluble and particulate phosphorus transformations and deposition/scouring of particulate phosphorus from the stream bed were included in the in-stream model. The model was calibrated using measured water quality data from four stations in the basin for the period 1997 to 2001.

2 - GIS and Weather SWAT Input Data

GIS data for topography, soils, land cover, and streams were used in the SWAT model. An ArcView GIS interface generates model inputs from commonly available GIS data. These GIS data were summarized by the interface and converted to simple text files usable by the model. Observed temperature and precipitation were incorporated. These data were the most current data archived at the time of compilation.

Topography

Topography was defined by an elevation grid (Figure 2.1). Seamless elevation grids for the United States were available for downloading via the USGS Seamless Data Distribution System (http://seamless.usgs.gov/viewer.htm). The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Soils

Soil GIS data were required by SWAT to define soil characteristics (Figure 2.2). SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes for each soil. STATSGO GIS data were taken from the (Better Assessment Science Integrating Point and Non-point Sources) BASINS dataset, available online at http://www.epa.gov/OST/BASINS/.

Land Cover

Land cover was perhaps the most important GIS data used in the model (Figure 2.3). The land cover theme affects the amount and distribution of pasture and forest in the basin. These land covers were radically different. Forested areas contribute little to the nutrient loading, while pastures are thought to be the primary source of non-point source nutrients. It is important that land cover data be based on the most current data available, since land cover changes over time. Land cover was derived from 30 meter Landsat 7 ETM+ imagery by Applied Analysis Incorporated.

The small grains/row crop category was further refined due to the relatively high nutrient loads from this land cover. The classification for row/crop small grains was based on bare soil. However, there are areas in the basin which are not cultivated that may have significant bare soil. Roads and bare stream channels were sometimes missclassified as row crop/small grains. Occurrences of row crop/small grains on known roads or stream channels were reclassified. The area of each occurrence of row crop/small grains was also used to determine likely misclassifications. Since it was unlikely that anyone would cultivate a field of less than three acres, occurrences of row crop/small grains less than three acres were reclassified as over grazed pasture.

Subbasin Delineation

The subbasin layout was defined by SWAT using the DEM, a stream burn-in theme, and a table of additional outlets. The stream burn-in theme consisted of digitized streams; its purpose was to help SWAT define stream locations correctly in flat topography. A modified reach3 file from the US Environmental Protections Agency's BASINS model was used. The theme was modified to remove the outline of Lake Tenkiller, which the model confused with a stream path. Model predictions were only available at subbasin outlets, so additional outlets were added at points of interest such as gages or water quality sampling sites. A stream threshold value of 3,000 ha was used to delineate

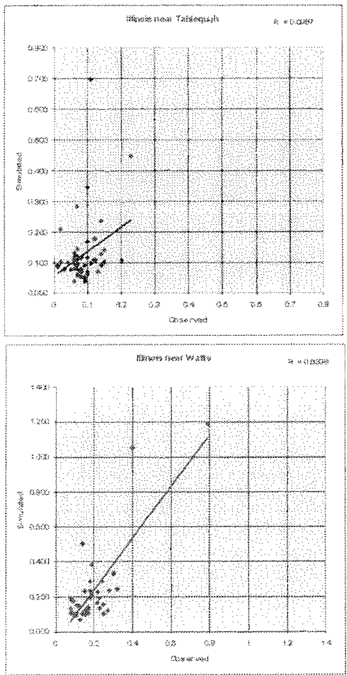

Figure 8.4 Observed and daily predicted total phosphorus concentrations. Predictions based on the calibrated SWAT and in-stream models.

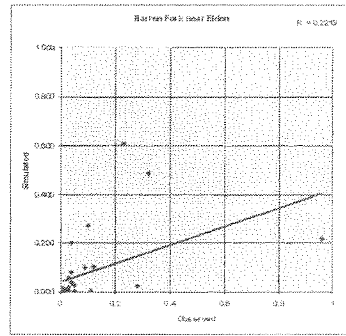

Figure 8.4 Observed and daily predicted total phosphorus concentrations. Predictions based on the calibrated SWAT and in-stream models. (Continued)

9 - Results and Conclusions

Load Sources

The SWAT model was used to predict the basin load allocation by land cover (Figure 9.1). The application of litter increased the per unit area load from pastures. However, unfertilized heavily utilized pastures were also major contributors. The model predicted that well managed pastures receiving litter had a similar per unit area total phosphorus load to unfertilized over grazed pastures. However, this effect was partially due to elevated STP even in non-littered pastures.

Phosphorus contributions to Lake Tenkiller were broken down by source in Figures 9.2 and 9.3. The models indicated that 35% of the total phosphorus reaching the lake was from point sources. The application of poultry litter was responsible for 15% of the total phosphorus load. This does not include the effect of increased soil phosphorus from years of poultry litter application, which increased total phosphorus load. Therefore, if litter application was suddenly eliminated, the phosphorus load would be reduced by approximately 15%. Total phosphorus load due only to elevated soil phosphorous from the application of litter was not estimated.

Meeting the 0.037 mg/l Oklahoma Criterion

A main focus of this project was to estimate the level of litter export and point source phosphorus reductions that were needed to meet the 0.037 mg/l Oklahoma criterion. The model predicted total phosphorus concentration on a daily basis, and thus we elected to assume a sample was collected each day for the purpose of calculating the geometric mean. This was more samples than the standard required, but was done to ensure there was no effect of sampling schedule. The 0.037 mg/l criterion was calculated based on the follows:

> 785:46-15-10. Nutrients, *(h) Special provisions for Scenic Rivers. (1) Scope and applicability. This subsection (h) shall be used to determine whether the beneficial use of Aesthetics designated for a segment of a Scenic River is supported with respect to the criterion of total phosphorus. (2) Data and procedure. (A) The data used shall satisfy all of the requirements of 785:46-15-3 except subsection (f) thereof. Notwithstanding such requirements, the data shall include samples collected from stream flow of at least six (6) storm events per calendar year or, if fewer than nine (9) storm events occurred in that year, then the majority of the storm events that occurred that year. (B) Whenever multiple samples are taken from a single storm event, the event mean concentration shall be determined and used as representative of that storm event. (C) A three-calendar-month geometric mean concentration shall be determined each month using the total phosphorus data from that month together with such data from the preceding two calendar months. (3) Support tests. (A) The Aesthetics beneficial use designated for a segment of a Scenic River shall be deemed to be supported with respect to total phosphorus if less than 25% of the monthly determinations made in accordance with (h)(2)(C) of this Section exceed 0.037 mg/L total phosphorus. (B) The Aesthetics beneficial use designated for a segment of a Scenic River shall be deemed to be not supported with respect to total phosphorus if 25% or greater of the monthly determinations made in accordance with (h)(2)(C) of this Section exceed 0.037 mg/L total phosphorus.*
>
> *[Source: Added at 17 Ok Reg 1775, eff 7-1-00; Amended at 18 Ok Reg 3379, eff 8-13-01; Amended at 21 Ok Reg 1910, eff 7-1-2004; Amended at 22 Ok Reg eff 7-1-2005]*

We simulated litter export from 0% to 100% and point source concentrations from current levels to

0.25 mg/l (Table 9.1). Each simulation was evaluated against the 0.037 mg/L criterion. Point source reductions had a much larger impact on the geometric means than litter export. For example, even with 100% litter export, three stations still had geometric means in excess of 0.037 mg/l 100% of the time. Barron Fork was the only area that currently meets the criterion, almost certainly due to the lack of a major point source. Model simulation were repeated using 20 year design flows as estimated by DEQ. Design flows are given in Table 9.4, model prediction are given in Table 9.5.

Lake Tenkiller Phosphorus Load

The model predicted that 330,000 kg/yr of total phosphorus reached Lake Tenkiller between 1997 and 2001. Of that 88,000 kg/yr was in soluble mineral forms. Predicted daily loads to Lake Tenkiller were plotted in Figure 9.4, and monthly loads given in Figure 9.5. The model predicted that in excess of 60,000 kg of phosphorus was transported to the lake in a single day in early January 1998. The model predicted that these extreme events wash out phosphorus stored in the sediments of the Illinois River and its tributaries. This event occurred in a month with a 250,000 kg reduction is stored phosphorus in as shown in Figure 7.3. It is possible for the average annual phosphorus load predicted by SWAT (330,000 kg/ yr) could be transported in a few days during some of the more extreme events.

Achieving a 75% Total Phosphorus Load Reduction

The ODEQ requested that we identify possible reduction scenarios to meet a 75% reduction of total phosphorus load to Lake Tenkiller. Achieving a 75% reduction will require significant changes in the basin. The following is a list of possible actions and the resulting reduction in phosphorus load to Lake Tenkiller based on our model predictions. Note that the pasture scenarios are mutually exclusive.

Practice or modification	***Reduction***
Mutually Exclusive (Only one scenario at a time)	
No over grazed pasture	6%
Replacement of litter with commercial nitrogen	22%
Hay pasture only, no cattle	21%
Hay pasture only, no cattle, and replacement of litter with commercial nitrogen	34%
Convert all pastures to forest	55%
Non-mutually Exclusive (Add one or more with a single mutually exclusive pasture scenario)	
No point source phosphorus discharge	35%
Halt all row crop/small grains cultivation	1%

Our model predicts that the only way to reach a 75% reduction would be to convert some pasture to forest, eliminating all row crop/small grains, litter, cattle, and point sources and cutting pastures for hay only will reduce the load by (34%+35%+1%) = 70%. Converting all pasture to forest and eliminating point sources will reduce the load by (55%+35%) = 90%. A 75% reduction lies somewhere between these two scenarios. Eliminating all row crop/small grains, litter, cattle, and point sources and cutting pastures for hay only, and converting 25% of pasture to forest would result in approximately a 75% (75% ≈ (90%-70%) * 25% + 70%) reduction. There are other fractional combination of the scenarios that result in a 75% reduction, but we do not have model runs to support the fractional scenarios.

Point Source Reductions Required to Meet Total Phosphorus Criterion

Point source reductions are the key to meeting the 0.037 mg/l total phosphorus criterion. The model predicts that reductions in litter application will have little effect upon the measured three month geometric means. This is not surprising since nonpoint sources generate loads which are very transient in nature. Non-point sources contribute only when significant runoff occurs. Loading from non-point source is extreme and infrequent. Geometric means are relatively insensitive to extreme values, and are a much better indicator of the median value. Point sources are constant dischargers which elevate the concentration uniformly. This uniform elevation is translated directly to increased geometric mean values. Table 9.3 contains an hypothetic example illustrating the properties of geometric means. In the example we propose that there are only three sources of the pollutant: background or natural sources, point sources, and non-point sources. Background load is one unit per day unless it rains (as on day five) when it becomes 11 units/day for a total of 20 units. Point sources are constant discharges and contribute one unit/day regardless of rainfall for a total of 10 units. Litter application is the non-point source and it contributes only when it rains, but contributes 10 units/day on that day for a total of 10 units. Point sources and non-point source both contribute a total of 10 units each and background is 20 units for a total of 40 units (25 % point source, 25% non-point source, and 50% background). The average of background + point source or background + non-point source are both three units/day, but the geometric means are 2.39 and 1.36, respectively. Adding point source to the background increased the geometric mean by 88% while adding only non-point source increased it by just 7%, a difference of more that one order of magnitude. The total units contributed and the arithmetic averages of these two scenarios are identical. Geometric means are insensitive to extreme values. Due to nature of a geometric mean, reductions in point source contributions must be the primary action required to meet the standard.

We do not need SWAT and an in-stream model to tell us we must reduce point sources to meet the standard, but these tools can be used to estimate what reductions are needed. We predict that point sources discharges will have to be reduce to 0.25 mg/l to meet the standard throughout the basin, and that reductions in litter application will not have a significant effect on supporting the standard. However, the application of litter remains a major contributor to the phosphorus load of Lake Tenkiller.

Model Limitations

Different portions of this study have different limitations. The upland model is much more robust than the analysis of in-stream geometric means. The in-stream model uses output from the upland SWAT model and is therefore subject to it's limitations as well as its own.

Upland SWAT Model Limitations

There are several limitations of the Illinois River SWAT model that should be noted. Limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is not perfect nor complete, and a model by definition is a simplification of the real world. Understanding the limitations helps assure that accurate inferences are drawn from model predictions.

Weather is the driving force for any hydrologic model and thus uncertainty in the rainfall or the rainfall distribution across the watershed is important. Great care was, therefore, taken to include as much accurate, observed weather data as possible. The inclusion of NEXRAD derived weather data should improve the accuracy of the model and reduce this limitation. However, this was not evaluated in this study. Rainfall is estimated on a 4 km grid. Rainfall can be quite variable even within a single grid cell, especially in the spring and summer when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at one location, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence since they are typically not additive.

Scenarios involving radical departures from calibration conditions result in greater uncertainty.

Although calibration assures the user that the results reflect the range of conditions encountered at the watershed, they do not assure the model will be accurate for drastic changes in land use or management.

Only major point sources were included in this analysis, although there are many other minor sources in the basin. These other sources, such as non-poultry CAFOs, and small communities, were considered negligible.

There is uncertainty associated with specifying uniform management for a land cover category. It is not practical to specify management for every field in the basin, and thus a typical management was selected and applied basin-wide for each land cover type. Management operations include grazing, fertilization, tillage, planting, and harvesting.

In-Stream Model Limitations

A model can only be as good as the data used in it. To accurately assess the 0.037 mg/l Oklahoma criterion more data are needed. A geometric mean by it nature is much more sensitive to base flow concentration than transient events. Nonpoint source pollution happens during rainfall events. Each event produces a slug of material that moves through the Illinois River and its tributaries relatively quickly. Although each event may result in very high in-stream total P concentrations, the impact on the geometric mean is relatively small. Based on our model predictions, nonpoint source pollution has little influence on whether or not the 0.037 mg/l criterion is met.

The in-stream model presented here is experimental, and has not been extensive validated. It is valid only at the location for which it was calibrated and validated, and still contains significant uncertainty. Dominant in-stream nutrient conversions vary by reach and through time. The in-stream model is a simplistic representation which contains errors, the amount of error is unknown.

The models were unable to match observed data for Flint Creek, which could be the result of poor observed data, structural model inadequacies, or inaccurate model parameter estimates. The models perform better is some areas that in others. It is not possible to quantify how the models perform at locations for which we have no data. This adds considerable uncertainty in these predictions.

Most WWTP have fairly constant discharges, and thus all the point sources were treated as constant monthly discharges in the model. Six out of nine points sources had measured total P concentration data. All major points sources in the basin had at least some measure data on which to estimate loads. In lieu of measured data we made estimates of concentration based on the type of treatment.

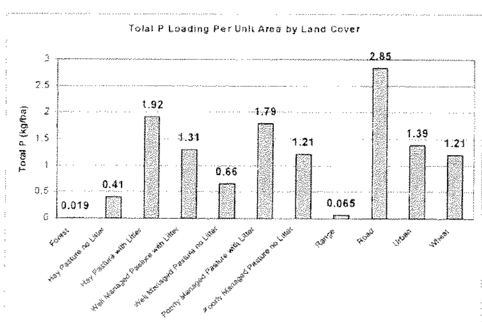

Figure 9.1 Total phosphorus load per unit area from upland areas by land cover as predicted by the SWAT model in the Illinois River basin (1997-2001).

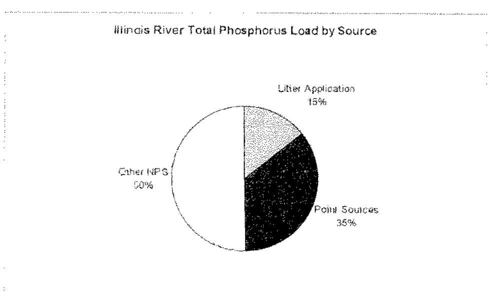

Figure 9.2 Total phosphorus reaching lake Tenkiller by source as predicted by the SWAT and in-stream models (1997-2001).

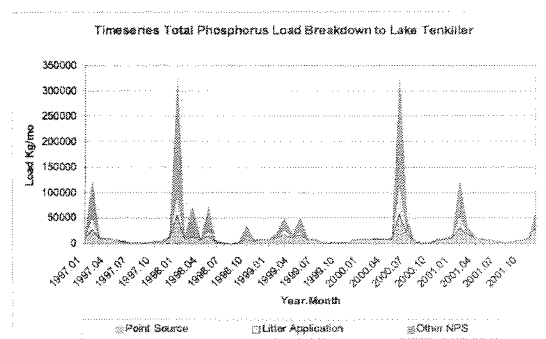

Figure 9.3 Total phosphorus reaching lake Tenkiller by source as predicted by the SWAT and in-stream models. Monthly time-series1997-2001.